ELECTRICAL AND MECHANICAL DESIGN OF THE DECADE QUAD IN PRS MODE*

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Abstract

The electrical and mechanical design of the Decade Quad Plasma Radiation Source (PRS) mode is described. The primary design criteria and assumptions, key component schematics and a discussion of compatibility with future advanced loads are given.

I. INTRODUCTION

The official IOC date for the Decade Quad NWE Simulator[1] is August, 1999. At that time the Decade Radiation Test Facility will be operational at the Arnold Engineering and Development Center in Tullahoma, Tennessee. In its initial configuration[2], the Quad will have four large area bremsstrahlung (LAB) loads that combined will produce an x-ray dose of at least 16 krad (Si) over an area of at least 2250 cm^2. An optimization program aimed at increasing the simulator performance capabilities, definitively mapping the radiation output and improving the facility's overall operational efficiency will run from August to January, 2000. At that time preparations will begin to assemble and test the modifications to the Quad needed to couple the electrical power from the four individual modules into a single Plasma Radiation Source (PRS) load. The IOC date for this extended capability is August, 2000 (Figure 1). In this PRS mode the Quad is expected to deliver 10 MA to a short and 8 MA to a 300 ns imploding load and will produce at least 20 kJ of cold x-rays.

In addition to the 300 ns imploding load and short circuit current specifications, the design must also be compatible with: a POS rise time sharpener, alternate, shorter implosion time loads, and a monolithic opening switch to drive both advanced LAB or PRS loads.

DQ LAB IOC: August 1999
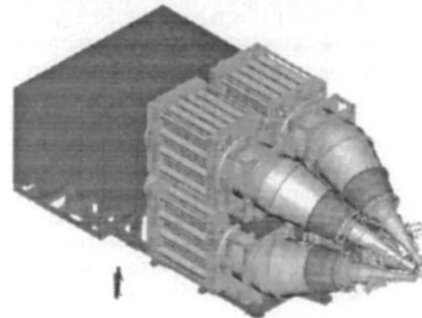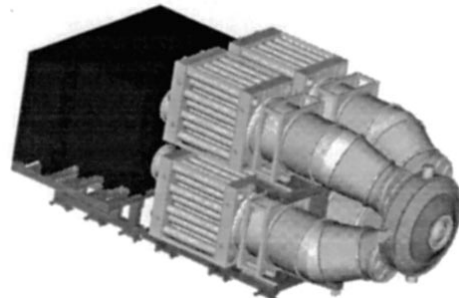
DQ PRS IOC: August 2000

Figure 1. The 2.5 MJ Decade Quad x-ray NWE simulator will be in operation at Arnold Engineering and Development Center in Tennessee starting in the fall of 1999. Its original configuration will be a LAB mode that generates hot, ~2 MV x-rays. In the fall of 2000, the PRS mode will be on-line generating cold, ~5 kV x-rays. The preliminary design of this latter mode is described herein.

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14. ABSTRACT
The electrical and mechanical design of the Decade Quad Plasma Radiation Source (PRS) mode is described. The primary design criteria and assumptions, key component schematics and a discussion of compatibility with future advanced loads are given.

15. SUBJECT TERMS

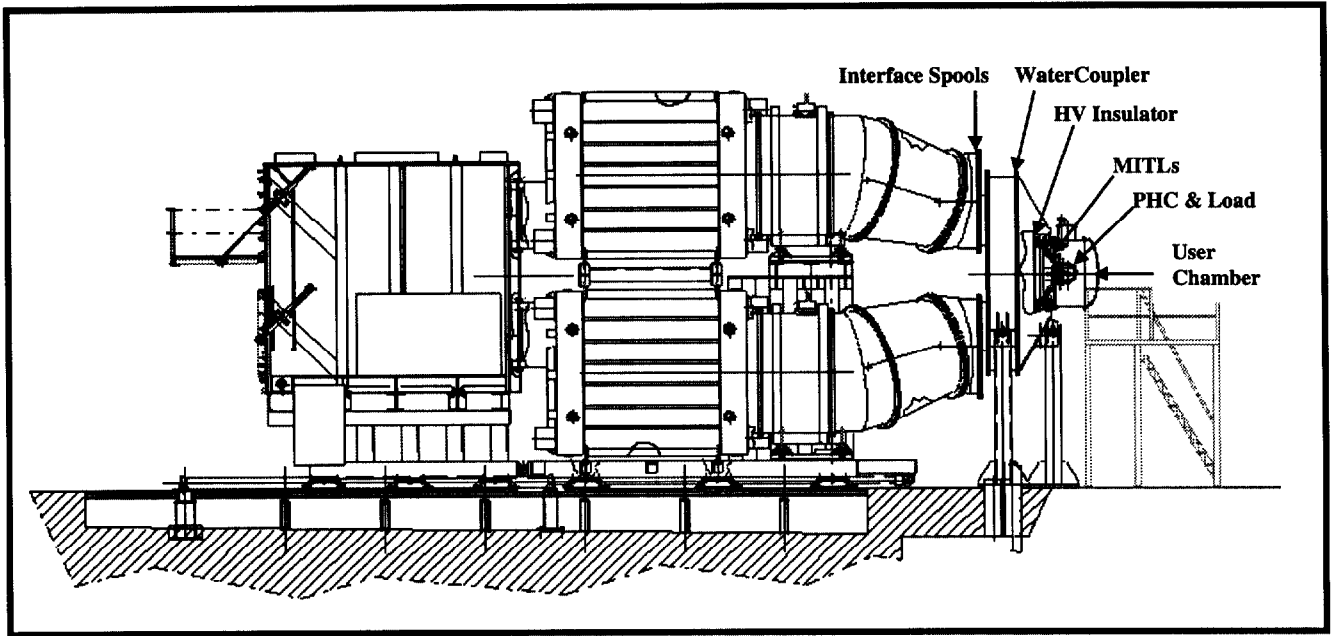| 16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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Figure 2. The Decade Quad in PRS mode configuration. The electrical power from the four Marx, transfer capacitor and output line modules is carried through four interface spools and combined in a triplate, conical, water-filled coupler. The power flows through a high voltage insulator stack, onto triconic MITLs, through a post-hole-convolute (PHC) and finally to a coaxial load. The conical coupler design allows 90° line-of-sight access to the imploding loads through twelve ports around the circumference of the user chamber.

Work prior to and through the system conceptual design explored the cost versus performance trades associated with the coupler/quad interface location selection[3]. Locations near the transfer capacitor output produce the shortest, least inductive coupler designs with the highest load currents. However, these designs are large, expensive and somewhat difficult to change-over between the LAB and PRS configurations. Each trend reverses as interface locations nearer the front-end are examined. In the end, a compromise at a mid location at the flange just downstream from the end of the DQ LAB Output Lines was chosen.

Figure 2 is a side view of the Decade Quad in its PRS mode configuration. The four LAB vacuum insulator stacks, MITLs and loads are removed and replaced with a conical, triplate water coupler that combines the electrical power from the four Marx modules. The combined 6 TW power flows down both sides of the 0.16 Ω equivalent, triplate coupler to a double-sided, high voltage insulator stack. The tube isolates the water insulated coupler from the vacuum insulated components downstream. On its vacuum side the tube is connected to a set of triconic MITLs each with an impedance of 2.5 Ω. The conical MITLs connect to a single radial feed MITL through a Post-Hole-Convolute and the PRS load is fed by this radial MITL. The equivalent inductance of the converging coupler and vacuum region is 11.2 nH including the initial load.

II. ELECTRICAL DESIGN AND PERFORMANCE PREDICTIONS

One dimensional TLCODE[4] circuit model calculations are used to predict the voltage and current waveforms (Figure 3) and to assess the design's tolerance to electrical breakdown and fault modes. A two dimensional TL2D model was used to investigate the front-to-back current symmetry in the coupler.
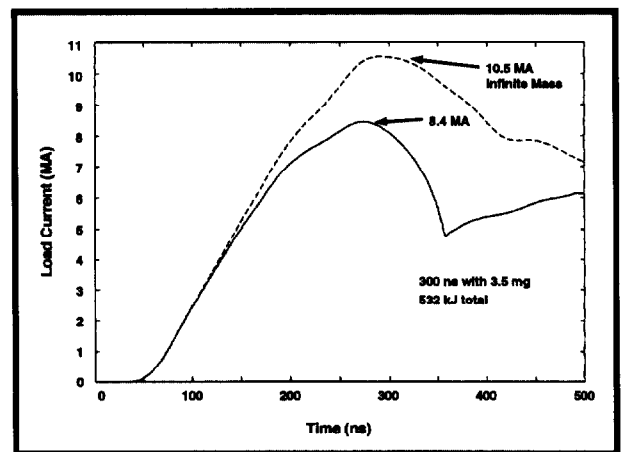

Figure 3. 1-D model load current predictions. The imploding load parameters are modeled to match those for a 300 ns, uniform fill, 4.0 cm long Argon puff with $\eta^* = 1.5$ (6 cm radius). 20:1 compression is assumed. The shorted load has this same geometry with an infinite mass rod replacing the puff.

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A goal was adopted to impress the same electrical breakdown criteria on the DQ PRS design as was used to develop the DQ LAB design. In principle, this guarantees that each has roughly the same reliability. This is possible for the 300 ns PRS load (Table 1).

Table 1. DQ PRS Electrical Breakdown Criteria for 300 ns Imploding Load Configuration

Criteria	Goal	Design
Water Stress[1]	86.9% JCM	83.6% JCM
Diaphragms	E_i < 80 kV/cm	< 79.2 kV/cm
Vacuum Flashover[2]	68.9% JCM	69.0% JCM
MITL Insulation[3]	< 250 kV/cm	< 250 kV/cm

1. 80.2% one module (DM1 performance)
2. 60% one module
3. Until V/IZ < 1/3

The electrical stress levels will change for each alternative load listed in the introduction. Higher voltages and electrical stress will occur in the legacy water filled output lines when the effective impedance downstream is higher than that in the LAB mode. As a result, it was not possible to extend the breakdown criteria across all the desired modes of operation.

For shorter implosion time loads, the stress levels increase. For example, at about 200 ns, the water stress rises to 92.4% JCM and the vacuum insulator stres levels increase to > 95% JCM. This water stress will likely cause problems; the vacuum stack stress is routinely exceeded in the high current PRS drivers at Sandia. The DQ Marx charge voltage will likely have to be reduced unless either a large or small radius, monolithic POS is used to reduce the drive risetime for < 200 ns implosions. Circuit models with opening switches show that the water stress can be reduced to acceptable levels.

Compatibility with advanced LAB loads require limiting the front end inductance to approximately 14 nH to keep the water stress at acceptable levels.

III. MECHANICAL DESIGN DESCRIPTION

1) Interface Spools

The interface of the coupler to the legacy Decade Quad hardware was carefully selected as a trade-off between performance (reduced coupler length and inductance) and cost (reduced coupler diameter). An optimum exists at the four flanges to which the LAB insulators mount which are downstream from the large Output Line bends that cause the LAB front-ends to converge. The interface spools (Figure 4) are themselves large elbows that undo the output line bend and return the hardware to an upright plane that more suitably accommodates the shim adjustments and alignments required to connect to the large coupler.

In addition to providing adjustability for both the cathode and anode, the spools also contain a dielectric diaphragm across the AK gap that isolates the Transfer Capacitor and Output Line water systems from the coupler's 10 psig water system. This keeps the added force due to the increased water head (from the coupler) from acting on the lower Transfer Capacitors.

Access through a removable cover plate on the cathode spool allows technicians to inspect and maintain the output switches without splitting the Quad at the Transfer Capacitor/Output Line interface. This simple feature significantly reduces the time and manpower needed for this routine task.

2) Water Coupler

The conical coupler design (Figures 4 and 5) was selected over several other candidate configurations based on superior electrical performance, mechanical strength, load access and manufacturability.
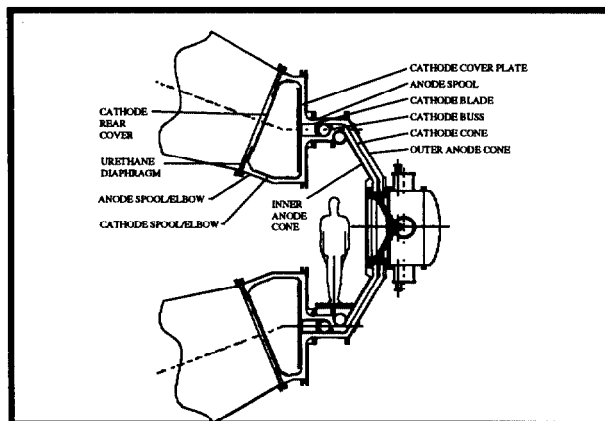

Figure 4. The DQ PRS conical, triplate water coupler combines the electrical power from the four Marx modules. Power flows evenly down both sides of the triplate coupler to a double-sided, high voltage insulator stack and eventually on to the load.
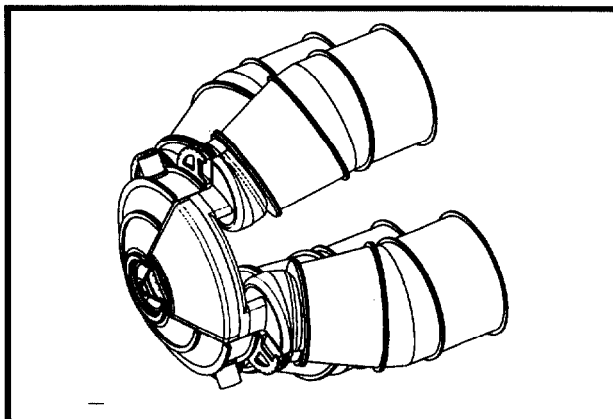

Figure 5. The coupler connects to the four interface spools through the cathode blades. An annular cover (cut-away in this schematic) provides the rear closure between the spools and the two anode cones.

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The inner and outer anode cones are each constructed in two sections from 0.5 inch thick, 304 stainless steel. The cathode will be built from a single roll-up with a thickness of 0.5 inch. The AK gaps are 3.0 inch outside a 50 inch radius and 2.5 inch inside. The tolerancing will allow these gaps to be maintained within ± 5% under static conditions. The design will permit variation of these gaps to trim the electrical performance by inserting spacers at the cathode blades, the anode cone section breaks and the insulator.

3) Insulator Stack

The +6%, -7% graded, high voltage insulator stack assembly is mounted on a horizontal axis. It is the water/vacuum interface between the water coupler and the vacuum MITLs (Figure 6). The individual 48' diameter, 45° Rexolite™ insulator and stainless steel gradient rings are pre-loaded to 37000 lbs by 24 circumferential Torlon 4203 tie rods. With this pre-loading the stack is stiff enough to be cantilevered from one end ring without suffering slipping at any insulator interfaces. Rigid face seals and current connections at its ends are made to the front and rear anode cones and a rigid connection is made to the cathode cone at its midplane.

The stack is designed to hold-off 640 kV on the main pulse and a implosion spike that reaches 970 kV. In these two cases the ring backs on the water side are stressed to 122 kV/cm (50% JCM) and 184 kV/cm (63% JCM) respectively. The flashover stresses are 72 kV/cm (69% JCM) and 109 kV/cm (63% JCM). The fields on the gradient ring tips are < 253 kV/cm during the main pulse and are therefore not expected to emit.
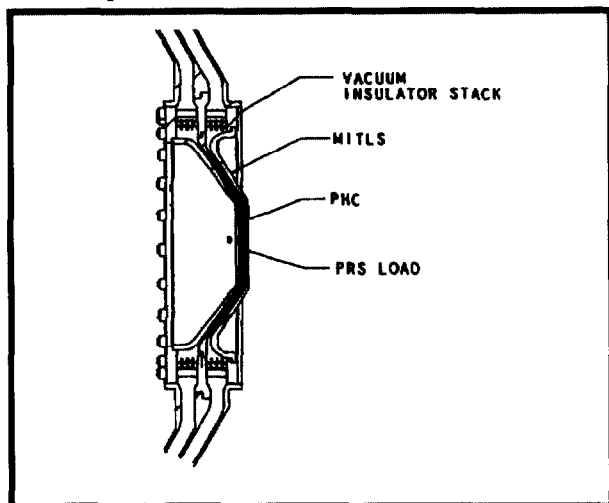

Figure 6. The DQ PRS high voltage insulator stack is based on the Saturn and Z points of departure[5]. The design is compatible with rubber, polyurethane rings which could be installed later pending the lifetime performance of the baseline plastic rings. Access to the MITLs and load is designed to accommodate rapid replacement and cleaning after each shot.

4) MITLs and PHC

The triconic MITLs are the vacuum transmission lines that connect the insulator stack to the post-hole-convolute (PHC). The AK gap in each constant 2.5 Ω MITL tapers down from the vacuum flare region just downstream from the tube to a minimum of 1 cm at a radius of 24 cm. All the conductors are fabricated from stainless steel.

The PHC connects the triconic MITLs to a single, final, radial feed MITL. The architecture is similar to the upper portions of the Saturn and Z convolutes. The gaps between the posts and the holes is held to 1 cm.

IV. DESIGN STATUS

At this writing all previously discussed elements have passed preliminary design. Some iteration of the insulator electrical and mechanical design is on-going prior to initiating engineering drawing efforts on the main coupler hardware and user chamber. A final, critical design review will be held in August, 1999.

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V. ACKNOWLEDGEMENTS